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SCIENCE DIRECT®
Coastal Engineering 53 (2006) 209 – 222
Coastal Engineering
An International Journal for Coastal, Harbour and Offshore Engineers
www.elsevier.com/locate/coastaleng

Modelling infragravity motions on a rip-channel beach

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Available online 28 November 2005

Abstract

A non-linear shallow water wave model operating on the time-scale of wave groups is compared with measurements of infragravity motions on a rip-channel beach to verify the model concepts and assess the model performance. The measurements were obtained during the RIP-current EXperiment (RIPEX) in concert with the Steep Beach Experiment (SBE) performed at Sand City, Monterey Bay, CA, during the spring of 2001. The nearshore bathymetry was made up of shore-connected shoals incised by relatively narrow rip-channels spaced approximately 125 m apart. The comparison considers a 20-day period during which significant changes in both the offshore wave climate and nearshore bathymetry occurred. The temporal variation in infragravity conditions during the experiment is strong, with computational results typically explaining 70% to 80% of the observed infragravity motions within the nearshore. In contrast to the temporal variation, the alongshore spatial variation in infragravity intensity during the experiment is generally weak, even though the underlying bathymetry shows strong depth variations. Model computations suggest preferential coupling between the computed edge wave motions and the quasi-periodic bathymetry is present, a prerequisite for strong spatial variability. However, the infragravity field is dominated by cross-shore infragravity motions, which are only weakly coupled to the quasi-periodic bathymetry, resulting in a weak alongshore variability of the total infragravity motions.

Keywords: Infragravity waves; Rip-channels; Edge waves; Numerical modelling; Field measurements; Alongshore variability; Bathymetric coupling

1. Introduction

Infragravity waves with periods between 20 s to 5 min are generally associated with the groupiness, or the beat, of the incident waves (Munk, 1949; Tucker, 1950). The infragravity wave field is typically made up of both leaky, i.e. infragravity waves that radiate away from the surfzone, and trapped long waves (edge waves) that cannot escape from the shoreline due to strong refraction. Previous measurements (Suhayda, 1974; Huntley, 1976; Holman, 1981; Wright et al., 1982; Guza and Thornton, 1985, among others) have shown the increased contribution of infragravity motions to the total gravity wave spectrum with decreasing water depth. This effect is associated with the wave-breaking induced saturation of the incident waves, whereas the infragravity waves continue to shoal without breaking, consequently their relative contribution increases rapidly as the shoreline is approached and can reach energy levels significantly higher than the incident wind waves (Wright et al., 1982; Guza and Thornton, 1985). Infragravity waves are therefore important in wave overtopping and run-up on dikes and dunes (Van Gent, 2001) as well as dune erosion (Overton and Fischer, 1988). The related safety of the hinterland calls for reliable model predictions of infragravity waves under a wide range of conditions.

So far, comparisons of computed infragravity conditions with field data have been limited. List (1992) compared his 1D-model with data obtained at Duck, North Carolina to explain the release of bound long waves within the surfzone. Reniers et al. (2002) used a linear 1D spectral model and measurement-data from the DELILAH field experiment (Thornton and Kim, 1993) and obtained favorable comparisons for the infragravity conditions. A subset of that data was utilized by Van Dongeren et al. (2003) in a comparison with a 2D non-linear model that showed the beach at the time of the DELILAH experiment could be considered as being alongshore uniform for the infragravity conditions.

The presence of alongshore variability in the bathymetry is expected to be important in view of the potential coupling between infragravity conditions and the underlying bathymetry

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doi:10.1016/j.coastaleng.2005.10.010

(Bowen and Inman, 1971; Holman and Bowen, 1982; Chen and Guza, 1998; 1999), resulting in a strongly inhomogeneous infragravity field. However, measurements of infragravity motions often give little idea about the alongshore variation of infragravity conditions due to the fact that the measurements are isolated (Elgar et al., 1992; Okihiro et al., 1992), or restricted to the cross-shore (Huntley, 1976; Guza and Thornton, 1985; Ruessink, 1998a), or performed at what would be considered an alongshore uniform beach (Huntley et al., 1981; Oltman-Shay and Guza, 1987; Herbers et al., 1995). Most notably, measurements at a number of beaches in South-Eastern Australia suggested the expected coupling between (complex) nearshore bathymetry and the infragravity (edge-)wave field (Wright et al., 1979), due to the presence of preferentially forced infragravity frequencies in the measured surface elevation and velocity spectra. Although these experiments were rich in morphological contrast, the number of instruments was typically limited (five or less within the nearshore) and information on the adjacent bathymetry, a requirement for modelling efforts, was sparse.

The main objective of this paper is to verify the numerical modelling of infragravity conditions on an alongshore variable beach. Measurements of infragravity motions during the RIP-current field EXperiment (RIPEX) in concert with the Steep Beach Experiment (SBE) at Sand City, Monterey Bay, are used for comparison with the numerical model results. The bathymetry was repeatedly surveyed to produce a high resolution bathymetry time series. During most of the year, the beach at this location consists of shore-connected shoals incised by narrow rip-channels with an alongshore spacing of 100–250 m. A detailed description of the experiment and the analysis of the measured infragravity motions is given in the paper by MacMahan et al. (2004a).

The model approach, briefly described in Section 2, allows for directional spreading in the incident waves and the generation and propagation of leaky and trapped infragravity waves over an arbitrary 2D bathymetry utilizing the non-linear shallow water equations in conjunction with a wave driver that operates on the time-scale of wave groups (Reniers et al., 2004, denoted RRT04 hereafter). The model–measurement comparisons, spanning a period of 20 days, are described in Section 3. Comparisons focus on the temporal and spatial variation of the infragravity velocities and wave heights. During this exercise both the wave-breaking parameters and bottom friction coefficients are kept constant. The effects of the alongshore variability in the bathymetry are discussed in Section 4. Conclusions with respect to the model performance are given in Section 5.

2. Model description

A brief model description is given below. For a more detailed model description refer to RRT04. The numerical model utilized is an extended research version of Delft3D. Delft3D, developed by WL|Delft Hydraulics, is a comprehensive numerical model suite, which includes a wave driver, hydrodynamic flow, sediment transport, and morphologic response modules. The extensions considered in this paper are a more sophisticated wave driver to account for the effects of wave groupiness and the inclusion of surface rollers to describe wave breaking. Morphodynamic effects (RRT04) are not discussed in this paper, and model computations are performed over the measured fixed beds.

The wave driver considers the modulated wave energy associated with wave groups made up of the directionally spread spectral sea and swell components, to generate infragravity waves through triad interactions. A single summation random phase method (see Van Dongeren et al., 2003, for details) is utilized to generate surface elevation time series from the measured energy density frequency-direction wave spectrum, $E(f, \theta)$, at the offshore boundary. Applying a Hilbert transform to the surface elevation time series in combination with a low-pass filter yields the spatially and temporally modulated wave energy used as input for the wave driver. This energy, on the wave-group scale, is then propagated shoreward and released at wave breaking where it is first transferred to roller energy prior to dissipation, causing a spatial lag between the location of wave breaking and the actual dissipation (Nairn et al., 1990). Wave diffraction and wave–current interaction are neglected at present.

The temporal and spatial variation of the wave and roller energy are then used to calculate the radiation stresses. The mean and infragravity motions are solved using non-linear shallow water equations forced by the divergence of these radiation stresses to phase-resolve bound and free infragravity waves, both trapped (edge waves) and leaky.

The combined wave- and current bottom shear stresses are computed with the parameterization given by Soulsby et al. (1993) of the friction formulation of Fredsoe (1984). The parameterization is based on the current- and wave-only bed shear stress formulations and the angle between waves and flow. The drag coefficient, C_D, in the current shear stress is computed with Manning's formulation:

$$C_D = \frac{h^{\frac{1}{6}}}{n_m} \quad (1)$$

with n_m Manning's coefficient and h the local water depth. The wave friction factor in the wave-only bed shear stress is obtained with Swart's (1974) formulation.

Given the tidal variation, parts of the beach will become dry at low tide. To account for this, a procedure is applied that removes grid points during the falling of the tide and adds them during its rise (Stelling et al., 1986). If the water level at a velocity point gets below a threshold, the velocity point is set dry. If the water level becomes twice the threshold value, the point becomes wet again. A value of 0.2 m for the threshold is used in the computations.

3. Comparison with measurements

3.1. Introduction

During RIPEX-SBE, the offshore wave climate, measured with a directional Wave-Rider buoy 650 m offshore in a depth